Regional atmospheric response to tropical Pacific SST perturbations

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[1] An extended domain limited area model was implemented for seasonal-range simulations to assess the effect of tropical Pacific SST perturbations on weather patterns over Europe and Mediterranean. The experimental method consisted of Skiron/Eta model integrations with coarse and fine grid increment using artificially-modified as well as analysis SST forcing. The selected period was August–October 1997. Model simulations with coarse grid increment produced a weak signal in the precipitation pattern and the synoptic scale circulation over Europe, implying a damping of the North Atlantic atmospheric response to the tropical Pacific SST perturbation. Fine resolution experiments suggested an amplified dynamic response providing a direct link between tropical Pacific SST and North Atlantic synoptic circulation. The output signal is mainly attributed to the effective representation of the regional/mesoscale atmospheric features due to the model implementation with a fine mesh grid. **Citation:** Katsafados, P., A. Papadopoulos, and G. Kallos (2005), Regional atmospheric response to tropical Pacific SST perturbations, *Geophys. Res. Lett.*, *32*, L04806, doi:10.1029/2004GL021828.

1. Introduction

[2] The lower boundary conditions of the atmosphere such as SST, soil moisture, or snow coverage strongly affect the overlying atmospheric layers and produce meaningful features, especially on meso-β and even meso-α characteristic scales. Observational and numerical experiments have identified areas around the world where regional weather patterns are influenced by the tropical Pacific SST anomalies [e.g., *Ropelewski and Halpert*, 1987; *Frederiksen et al.*, 2001]. The atmospheric response to SST anomaly through a local, thermally direct modification in the circulation involves a deep convection anomaly and a shift in the mid-tropospheric centers of latent heat release [*Trenberth et al.*, 1998]. At the regional scale, the impacts from tropical Pacific SST anomalies are well documented in the literature since the end of the 80's [e.g., *Kiladis and Diaz*, 1989; *Ropelewski and Halpert*, 1996]. The research suggests that such low frequency disturbances are considerable in the entire intertropical region, especially in a zone which extends from South America to the Pacific and Indian Oceans.

[3] Several atmospheric GCM studies have also investigated the impact of prescribed SST anomalies over the North Atlantic but have failed to reach a consensus. *Robertson et al.* [2000] found different responses in two 10-yr-long experiments using a similar SST anomaly. *Lau and Nath* [1990] detected a NAO-like pattern to be substantially correlated with SST fluctuations over the tropical South Atlantic. However, the impact of the El Niño–Southern Oscillation (ENSO) on the North Atlantic circulation appears to be weak [*Graham et al.*, 1994] and most of these studies lack significant information on Europe and, in particular, the Mediterranean basin.

[4] The main purpose of this work is the investigation of the atmospheric response to the tropical Pacific SST anomalies. Whether such anomalies are amplified or damped in the atmospheric environment and how they affect (if at all) the synoptic or even the regional and mesoscale weather patterns has also been examined. In an effort to study the simulated effects of the tropical Pacific SST anomalies on Europe and Mediterranean, seasonal-range Limited Area Model (LAM) experiments were performed using both analysis as well as artificially-modified SST fields. The domain of LAM implementations has been extended from the tropical Pacific to the Caspian Sea and therefore could be considered as almost hemispheric (see Figure 1). To investigate the nature of the atmospheric response to imposed SST perturbations, a downscaling technique is implemented with both coarse and fine grid increment (also called as coarse and fine resolution) LAM experiments, forced by ECMWF analysis fields as initial and boundary conditions, in seasonal hindcasting mode. The main advantage of the downscaling approach is that it produces meaningful regional components for the exchange of heat, moisture and momentum established from the realistic representation of the mesoscale patterns in sub-GCM grid scale forcings [*Fennessy and Shukla*, 2000].

2. Experimental Design and Model Configuration

[5] Extended domain LAM experiments with perturbed surface boundary conditions are carried out to examine the response to SST anomalies in a realistic context. The implementations are based on two scenarios consisting of model integration with both analysis and artificially-modified SST forcing.

[6] • According to the first scenario, the ECMWF analysis SST fields are used (hereafter referred to as analysis SST) including the entire tropical Pacific SST anomaly during the period 1 August–31 October 1997 (hereafter referred to as simulation period), where the maximum departure from climatology has been detected. The specific gridded data set of $0.5° \times 0.5°$ horizontal grid increment is utilized for LAM surface boundary conditions with a temporal increment of 24 hours.

[7] • The second scenario consists of artificial lower boundary conditions constructed from both the ECMWF

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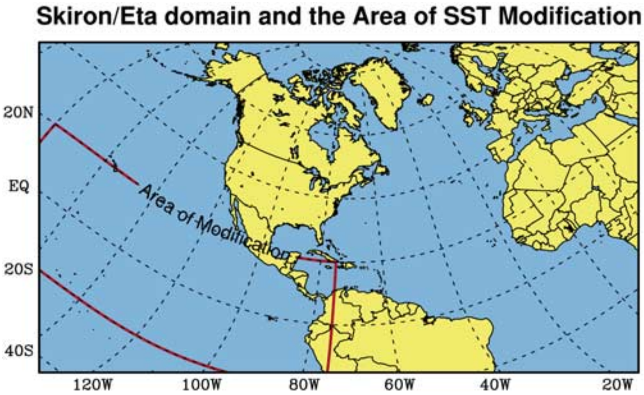

Figure 1. Skiron/Eta model integration domain for the experiments referred to in this study. Over the "Area of Modification", climatological SST values replaced the relevant analysis values in order to construct the artificially-modified SST fields.

analysis and climatological SST fields (hereafter referred to as artificially-modified SST). The climatological SST fields were produced from daily average values that have been prepared for each calendar day of the entire simulation period based on 16-year (1986–2001) analysis SST fields. At the grid points included in the area indicated in Figure 1 as "Area of Modification" (enclosed by the red line) the analysis SST has been replaced by the 16-year average values. The constructed SST fields have been smoothed in the area around the replaced grid points (5 grid points around the "Area of Modification") in order to avoid sharp gradients and consequently the generation of artifacts. The grid points of the domain outside this area have been kept unchanged.

[8] Two seasonal ensembles of five members initiated sequentially from 1 to 5 August are performed during the period August to October 1997 according to the prescribed scenarios. The LAM response to analysis and artificially-modified surface forcings is determined from the variation between the ensemble averages for each month of the reference period. Initial and boundary conditions have been obtained from the ECMWF analysis with 0.5° × 0.5° horizontal grid increment and 11 isobaric levels. The five members are necessary to obtain stable and reliable results, especially for any putative remote response to the SST perturbations. *Harzallah and Sadourny* [1995] suggested that it is necessary to perform a reasonable number of independent simulations with perturbed boundary (initial, lateral or surface) conditions rather than a single one in order to estimate the external (forced) atmospheric variability. The Student's t-test is used to assess confidence levels for differences in atmospheric response between simulations with analysis and artificially-modified surface boundary conditions. In an effort to identify the overall effect of the horizontal grid increment, the prescribed experimental design has been conducted with coarse and fine LAM integrations.

[9] The LAM applied in this study is a modified (at the University of Athens) version of the Eta/NCEP model (hereafter referred to as Skiron/Eta). A detailed description of the model dynamics and physics components is given by *Mesinger* [1973], *Janjic* [1994], and *Papadopoulos et al.* [2002]. For the performed experiments, a single extended domain of 1.00° × 1.00° (hereafter referred to as coarse) and 0.25° × 0.25° (hereafter referred to as fine) horizontal grid increment respectively has been defined (Table 1). In the vertical thirty-two unevenly spaced levels have also been specified. The Skiron/Eta implementation in seasonal hindcasting mode required modifications of the treatment of surface boundary conditions, especially over the water bodies. The analysis SST fields used are available every 24 hours. This is the time increment of updating the lower boundary condition for water surface temperature in the model. The 2-D ECMWF SST analysis fields have been interpolated at the model grid points and these points are masked as water. The ocean grid points with SST less than −1.78°C are masked as ice. This procedure was also followed for the simulations with the artificially-modified SST fields. For the soil temperature and moisture, interpolated ECMWF gridded data are used for six soil sublayers.

3. Results From Extended Domain LAM Experiments

[10] In general, the nature and the characteristics of the simulated atmospheric response to external forcings are mainly detected by modifications of the precipitation budget. Skiron/Eta model experiments, in coarse grid increment, demonstrated areas where the 30-day averaged precipitation differences (resulting from Skiron/Eta implementations with artificially-modified and analysis SST) exceeded the 95% of confidence level during the period of October 1997. Figure 2a depicts a strip over Western and Central Europe that does not exceed the lower limit of 0.25 mm/day, which is considered as statistically significant. According to the coarse resolution experiments, the tropical Pacific SST anomalies did not appear to be primarily responsible for the precipitation rate modifications over Europe and the Mediterranean region. The small differences in precipitation fields over Western and Central Europe can be considered as a signal of uncertainty. Fine resolution experiments show a more detailed spatial distribution of precipitation pattern. Figure 2b demonstrates an enhanced variability in the precipitation rate in October 1997, affecting regions similar to the coarse resolution experiments. More specifically, there is a strip of positive precipitation signal, which exceeds the 95% of confidence level, over Western Europe with local maxima of 2.1 mm/day over Alps and 1.7 mm/day over Spain. A secondary maximum of 1.4 mm/day is located in the Northern part of Morocco while Eastern Mediterranean regions showed

Table 1. Main Characteristics of the LAM Experiments

	Coarse	Fine
Coordinates at the corners of the domain	179.5°W, 60°E, 60.0°S, 90.0°N	
Horizontal resolution	1.0° × 1.0°	0.25° × 0.25°
Vertical resolution	32 unevenly spaced levels	
Simulated period	August-September-October 1997	
Initial and Boundary conditions	ECMWF, 0.5° × 0.5° resolution, global coverage, 11 isobaric levels	

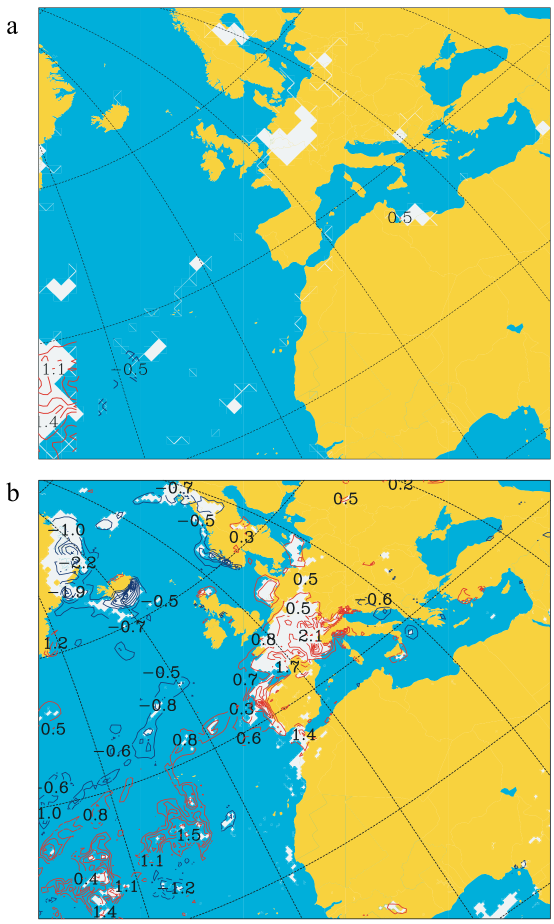

Figure 2. 30-day averaged differences (artificially-modified minus analysis SST) of precipitation rate (mm/day) valid for October 1997. Figure (a) refers to the LAM experiments with 1.00° × 1.00° resolution (coarse) and (b) with 0.25° × 0.25° resolution (fine). The contours denote the difference of the precipitation rate with increment of 0.25 mm/day while the areas exceeding the 95% confidence level are colored white. The red and blue contours correspond to the positive and negative differences respectively.

significant consistency in the precipitation patterns. A weaker response is also detected near the Azores but it is not considered as statistically significant. The positive signal is related with decreased precipitation during remote SST anomalies with a seasonal timescale response. Over the greater area of Iceland, a negative response is detected with minimum of −2.2 mm/day. This signal, as a response to the tropical Pacific SST perturbation, of the averaged precipitation differences has been resolved from fine resolution Skiron/Eta experiments, while simulations with coarse resolution produced almost negligible signals. LAM implementations on a fine mesh appear to play an important role in medium-range and seasonal-type simulations since they can resolve mesoscale features that are mainly due to surface inhomogeneities or topographic variability. These results indicate that the additional modes existing in fine resolution experiments contain a considerable amount of energy that is able to partially modify the basic synoptic patterns.

[11] In an effort to identify the atmospheric response to remote perturbations of the surface boundary conditions and better understand resolution issues, simulated time series of the mean sea level pressure (MSLP) over specific locations have been constructed. Both coarse and fine resolution

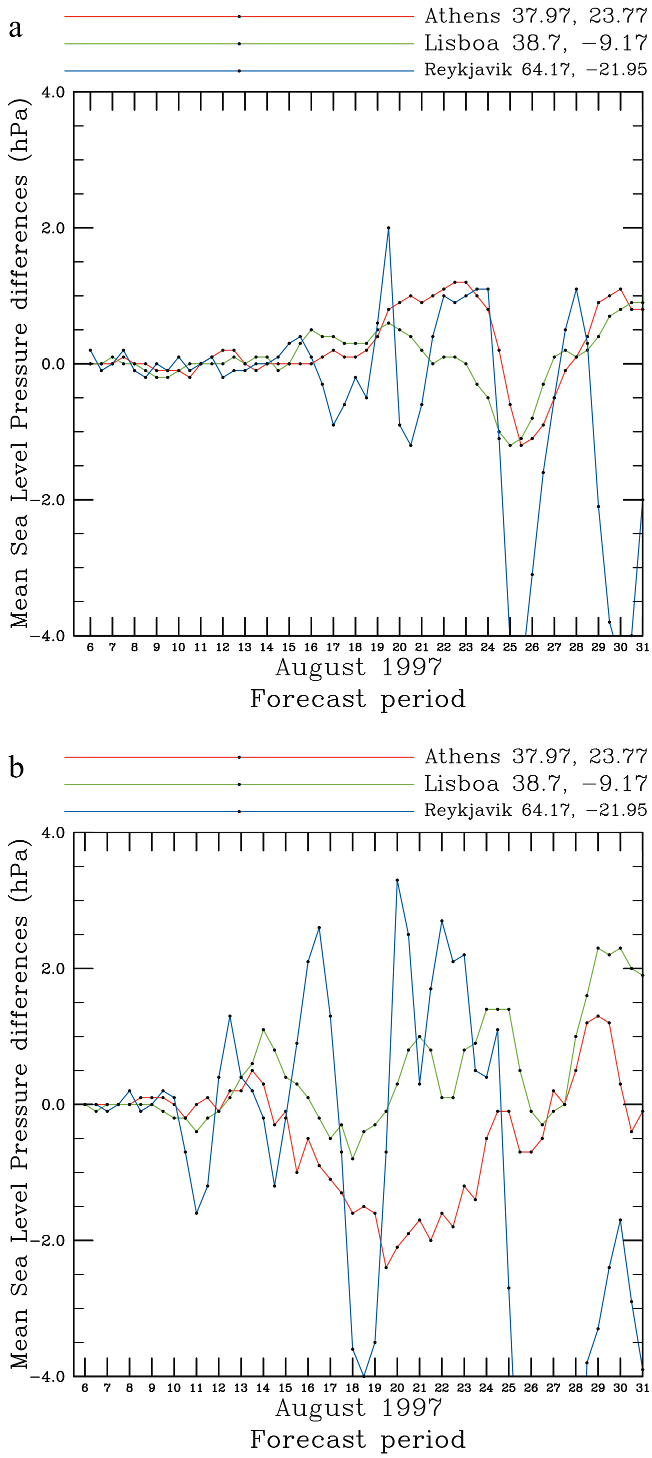

Figure 3. Temporal variation of the mean differences (artificially-modified minus analysis SST) for the MSLP (hPa) over 3 discrete locations during the first month of the simulation period. Figure (a) refers to the LAM experiments with 1.00° × 1.00° resolution (coarse) and (b) with 0.25° × 0.25° resolution (fine).

experiments show a significant response of the MSLP over Reykjavik, suggesting correspondence between SST and the Icelandic low, a prominent synoptic system over the North Atlantic basin (see Figure 3). According to the coarse resolution experiments, the MSLP differences over the area under consideration exceed the absolute threshold of 0.50 hPa over a period of 10–15 days from the time of model initializations. However, this is the estimated time lag for the propagation of a large-scale lower boundary perturbation in the computational domain (see Figure 3a). Lisbon exhibited a significant barometric signal with weaker amplitude over a similarly time lagged period, while Athens requires about four more days to exceed the prescribed threshold of ±0.50 hPa. Simulations with fine resolution exhibited similar time variation patterns of the MSLP differences (see Figure 3b). The maximum amplitude is still found over Reykjavik and it is considered as the most significant response. The fine grid LAM configuration resolved modes that fall within the mesoscale range of the spectrum and therefore propagate faster. Consistent with the fine resolution results, the required time of the MSLP differences to exceed the absolute threshold was reduced by four days. These particular results suggest that the simulated signals, as an atmospheric response to a remote oceanic thermal anomaly, could vary significantly according to the model grid increment.

4. Concluding Remarks

[12] Despite the difficulties in interpreting tropical Pacific SST experiments and reconciling the differences among them, the results obtained from this study suggest that the tropical ocean does indeed influence the atmospheric patterns over Europe and the Mediterranean.

[13] Various implementations of the modified Skiron/Eta model for the experimental period August–October 1997 were used to demonstrate the atmospheric response to remote SST perturbations. Coarse resolution experiments produced an almost negligible signal in the precipitation pattern over Europe. This pattern is preserved during the entire simulation period, implying a damping of the North Atlantic atmospheric response to the tropical Pacific SST perturbation. This could be attributed to the poor representation of significant atmospheric modes in the specific model configuration (absence of mesoscale features). In contrast, fine resolution experiments indicated an amplified dynamic response that is statistically significant over Europe. The present analysis showed that the centers and the gradients developed between the two anchor systems namely the Icelandic low and the North Atlantic (Azores) anticyclone are significantly affected by the tropical Pacific SST perturbations. In order to detect such effects there is need of proper model configuration (appropriate treatment of initial and boundary conditions) and of course proper resolution. The suggested model resolution lies within the range that is considered as appropriate for the description of mesoscale phenomena. Although our preliminary diagnoses indicate an interesting role for the tropical Pacific SST forcing, additional LAM experiments for several different periods with an even finer mesh grid are in the authors' near future plans.

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